Reproducibility of energy and macronutrient intake and related substrate oxidation rates in a buffet-type meal

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The aim of this present study was to determine the reliability of a buffet-type meal as a measure of spontaneous energy and macronutrient intake. In addition, we evaluated the short-term effects of diet on the composition of the substrate mix oxidized postprandially. Fourteen male subjects had *ad libitum* access to a variety of foods from a buffet-type meal offered in the laboratory during two identical sessions. The foods comprising the test meal had varying amounts of protein, lipid and carbohydrate. The results showed that there were significant intraclass correlations (r_i) for energy (r_i 0·97, $P = 0·0001$), lipid (r_i 0·97, $P = 0·0001$), carbohydrate (r_i 0·92, $P = 0·0003$) and protein (r_i 0·82, $P = 0·0072$) intake between the two meal sessions. Hunger and fullness levels measured immediately before and during 4 h after the meal were identical under the two conditions. In addition, there was no significant difference between the two sessions for RQ and resting energy expenditure, which showed significant reproducibility for measurements obtained immediately before, immediately after, as well as 30 min after, the buffet. This present study demonstrates the high reproducibility of energy and macronutrient intake and oxidation rate values obtained with a buffet-type meal in healthy male subjects and suggests that the use of this test is a reliable method for assessment of macronutrient preferences in the laboratory.

Food intake: Fullness: Hunger: Respiratory quotient: Energy expenditure

It has been suggested that the administration of a buffet-type meal in the laboratory could be an appropriate method for the accurate measurement of food intake (Rolls & Hammer, 1995; Tremblay & Saint-Pierre, 1996) because it offers an experimental context where energy intake and macronutrient preferences can be assessed. Even if standard buffet-type meals are often used to assess food intake (Rolls *et al.* 1994; Cook *et al.* 1997; Imbeault *et al.* 1997), their reproducibility in terms of energy and macronutrient intake has not been documented in the literature. The assessment of the reproducibility of a buffet meal is important because humans vary their food intake and nutrient selection from day-to-day (Tremblay *et al.* 1983; Obarzanek & Levitsky, 1985). This intra-individual variation can negatively affect the validity of studies using a buffet-type paradigm. Thus, a first aim of this present study was to evaluate the reproducibility of energy and macronutrient intake using a buffet-type meal.

The energy–macronutrient balance issue has been the object of numerous research observations over the last decades. This area of investigation was led by Flatt (Flatt *et al.* 1985; Flatt, 1995*a*,*b*) who emphasized the large difference in the accuracy with which carbohydrate and lipid balance are maintained stable. Specifically, it has been shown that an acute increase in lipid intake in response to a meal test does not result in an acute increase in lipid oxidation (Flatt *et al.* 1985; Rising *et al.* 1992; Horton *et al.* 1995; Larson *et al.* 1995*b*). Conversely, an increase in carbohydrate intake, be it small or more substantial, rapidly increased carbohydrate oxidation (Rising *et al.* 1992; Thomas *et al.* 1992; Larson *et al.* 1995*b*; Stubbs *et al.* 1997). To further investigate this issue, we took advantage of the present paradigm to evaluate the relationship between diet composition when one has free access to food in the context of a buffet-type meal and the composition of the substrate mix oxidized early after food intake in order to evaluate short-term macronutrient oxidation.

Methods

Subjects

Fourteen men, aged between 26 and 48 years, were recruited through advertisements and gave their written consent to participate in this study. Their physical characteristics are shown in Table 1. They were non-smokers, healthy, and sedentary to moderately active individuals. They were taking

Abbreviations: REE, resting energy expenditure; VAS, visual analogue scale.

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Table 1. Physical characteristics of the subjects (*n* 14)

Variables	Mean	SEM
Age (years)	38·3	2·1
Body mass (kg)	74·5	2·6
Height (m)	1·757	0·017
Body fat (%)	19·0	1·8
BMI (kg/m^2)	24·3	0·7

no medication and they were used to eating at breakfast and lunchtime. Their body weight was stable during the year preceding the study. Before initiating the protocol, all subjects completed a visual analogue scale (VAS) to ensure that they liked the foods served in the test meals. To be eligible to take part in the study, a subject had to rate at least 80 % of foods offered in the buffet at 50 mm or more on the 100 mm VAS (Rolls *et al.* 1994). Subjects were requested to avoid vigorous activities for at least 2 d before each experimental session. Although all subjects signed a consent form before the experimental protocol, they were not informed of the real purpose of this study. The consent form and the experimental protocol had previously been reviewed and approved by the Laval University Medical Ethics Committee.

Experimental sessions

Each subject was tested individually in two identical sessions (A and B) separated by at least 7 d. Subjects were instructed to eat as usual for the period covered by the protocol but to abstain from alcohol the evening before each experimental session. On each day of testing, the subject was asked to eat at home at 07.15 hours a standardized breakfast (2005 kJ) prepared by a dietitian from our team and nothing else except water was allowed until the buffet. The session started at 11.20 hours when the subject arrived at the laboratory. After a 30 min period of rest in the supine position, resting energy expenditure (REE) was measured for 15 min. At about 12.10 hours, a cold buffet-type meal comprising a variety of foods was offered and the subject was instructed to eat *ad libitum* (Table 2). Subjects took 20–40 min to eat their meal, except for one subject who took 60 min to eat *ad libitum*. Portions of each food were larger than the expected intake by the subject. Table 2 shows that there was a large diversity in the protein, lipid and carbohydrate content of foods in order to facilitate the detection of macronutrient preferences. All foods were weighed before the buffet and food items that were not consumed were reweighed after the end of the buffet to the nearest g to quantify the exact intake of each type of food. Energy, protein, lipid and carbohydrate intake were calculated using the Canadian Nutrient File (Department of National Health and Welfare Canada, Ottawa, Canada) and/or information on food labels. Immediately after the lunch, REE was measured for two 15 min periods with an interval rest

Table 2. Energy content and macronutrient composition of the food items presented in the buffet-type meal*

Food item	Initial amount (g)	Energy (kJ/kg)	Protein (g/kg)	Lipid (g/kg)	Carbohydrate (g/kg)
Sliced turkey breast	130	3930	160	34	0
Salmon and spinach mousse	90	10833	117	233	27
Liver pâté	70	13350	142	280	15
Sliced ham	150	5480	194	50	10
Sliced Swiss Gruyère cheese	100	17286	298	323	4
Mozzarella cheese	100	11718	275	171	31
Cottage cheese	100	3384	117	20	40
Butter	40	29990	9	811	1
Mayonnaise	60	30630	11	804	11
Italian dressing	60	26110	2	690	52
Mustard	30	3140	47	44	64
Ketchup	40	4350	15	4	273
White bread	150	11300	87	32	505
Wheat bread	150	10170	105	30	477
Soda crackers	100	18400	104	132	708
Sliced lettuce	60	670	16	2	24
Sliced tomato	100	880	9	3	46
Baby cut carrots	150	1800	10	2	101
Cored and sliced orange	100	1970	9	1	118
Sliced red apple	100	2470	2	4	153
Butter shortbread cookies	70	20840	72	231	651
Chocolate–almond cookies	100	19700	41	240	620
Fruit salad yogurt, stirred	250	4050	39	15	168
Milk (10 g fat/l)	1000	1754	33	11	47
Milk (20 g fat/l)	1000	2095	33	19	44
Milk (30 g fat/l)	1000	2549	33	33	47
Orange juice	1000	1826	8	2	109
Coca-cola	355	1720	0	0	104
7-up	355	1674	0	0	104
Regular crisps	60	23214	61	393	500
Water	1000				

*Energy, protein, lipid and carbohydrate content were calculated using the Canadian Nutrient File (Department of National Health and Welfare Canada, Ottawa, Canada) and/or information on food labels.

Table 3. Energy, carbohydrate, lipid and protein intake and food quotient in the two sessions of self-selection from a buffet-type meal
(Values are means and range with standard errors of the mean for fourteen male subjects)

Variable	Session A*			Session B*			Correlation		CV_{bs} (%)	CV_{ws} (%)
	Mean	Range	SEM	Mean	Range	SEM	r_i	P		
Energy intake (kJ)	7300	3471–13633	805·7	7011	3834–10567	532·8	0·97	0·0001	35·1	8·2
Protein intake (kJ)	1254	643–2732	146·7	1173	671–1669	73·8	0·82	0·0072	35·3	8·6
Percentage of energy intake	17·6		1·0	17·3		0·9				
Lipid intake (kJ)	2997	1395–5400	330·6	2965	1563–5017	253·3	0·97	0·0001	36·3	9·2
Percentage of energy intake	41·1		1·2	42·4		1·7				
Carbohydrate intake (kJ)	3050	1049–5502	364·4	2873	1306–5513	293·4	0·92	0·0003	41·1	10·8
Percentage of energy intake	41·3		1·4	40·4		1·7				
Food quotient	0·85	0·82–0·87	0·004	0·84	0·82–0·88	0·005	0·84	0·0026	1·9	0·8

r_i, intraclass correlation coefficient; CV_{bs}, between-subject coefficient of variation; CV_{ws}, within-subject coefficient of variation.
* There was no significant difference between the means of all variables in session A and B.

period of 15 min. Immediately before and after the buffet and every hour after the buffet for a period of 4 h, subjects completed a 100 mm VAS for the determination of hunger and fullness. Urine was collected at the end of the experimental session for Kjeldahl N analysis to calculate urinary N excretion.

Measurements

Body fat mass was determined using underwater weighing. The Siri equation (Siri, 1956) was used to estimate percentage body fat from body density. Residual lung volume was determined before hydrostatic weighing with the He dilution technique (Meneely & Kaltreider, 1949). REE and RQ were determined by respiratory gas exchange using an open-circuit computerized indirect calorimeter connected to a mouthpiece system. O_2 and CO_2 concentrations were determined by non-dispersive i.r. analysis (Uras 10 E, Hartmann & Braun, Frankfurt, Germany) whereas pulmonary ventilation determination was assessed with a S-430A measurement system (KL Engineering, Ventura, CA, USA). REE and RQ were evaluated for each subject three times during each session, following a 30 min rest in the supine position before the buffet-type meal, and immediately after and 30 min after the buffet. Measurements were taken over 15 min periods and the average of the last 10 min, when a steady state was established, was used to calculate REE and RQ. Substrate oxidation rates were calculated from consumed O_2 and CO_2 volume and urinary N excretion using classical equations (Jéquier *et al.* 1987).

Statistical analysis

For energy and macronutrient intake, ANOVA was used to estimate the reproducibility of the two sessions (inter-reproducibility) by comparison between the group mean for a given variable between sessions A and B. The reproducibility of each subject (intra-subject reproducibility) refers to the correspondence of each subject measurements between sessions and was evaluated by linear correlation analysis and intraclass correlation coefficients (r_i) between the individual values in sessions A and B. Additional information concerning variation of measurements between subjects and within a given individual was obtained by estimation of inter-subject (between) and intra-subject (within) variability which was expressed as CV (CV_{bs} and CV_{ws} respectively) for energy and macronutrient intake. For variables measured over time, repeated-measure ANOVA with session and time as the within-subject measurements was used to determine whether there were differences between sessions A and B over time.

Results

Table 3 shows that there were no significant differences in mean *ad libitum* energy and macronutrient intake between sessions A and B. Furthermore, a significant positive correlation was observed between the two sessions for energy, carbohydrate, lipid and protein intake and food quotient. The CV_{bs} of about 40 % for energy and macronutrient intake, which demonstrates that each subject showed individual difference in intake responses to the buffet-type

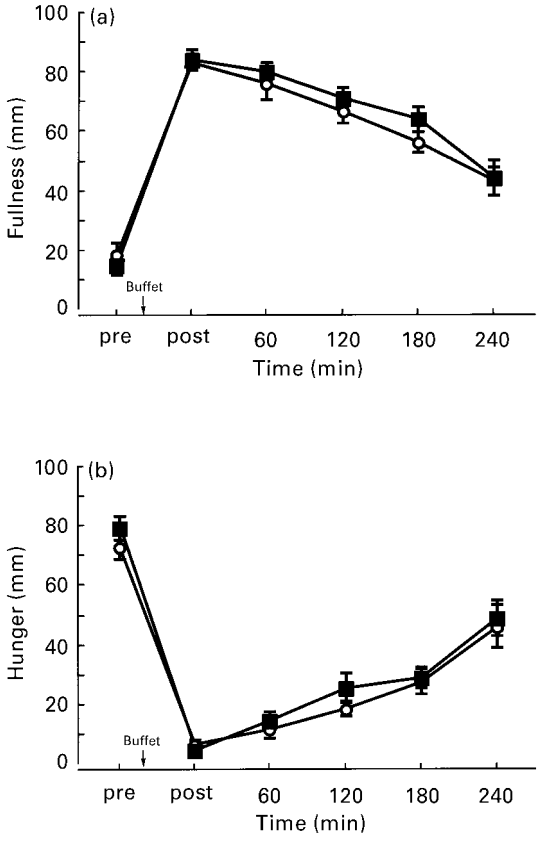

Fig. 1. Variations in (a) fullness and (b) hunger over time, as measured by a visual analogue scale, immediately before (pre) and 0 to 240 min after two sessions of self-selection from a buffet-type meal. Values are means for fourteen male subjects with standard errors of the mean represented by vertical bars. Repeated-measure ANOVA with session (S) and time (T) as the within-subject measurements was used to determine whether there were differences between sessions A (○) and B (■) over time and the interaction effect of S and T (S×T). Fullness: S, $P=0{\cdot}48$; T, $P=0{\cdot}0001$ and S×T, $P=0{\cdot}68$. Hunger: S, $P=0{\cdot}44$; T, $P=0{\cdot}0001$ and S×T, $P=0{\cdot}79$.

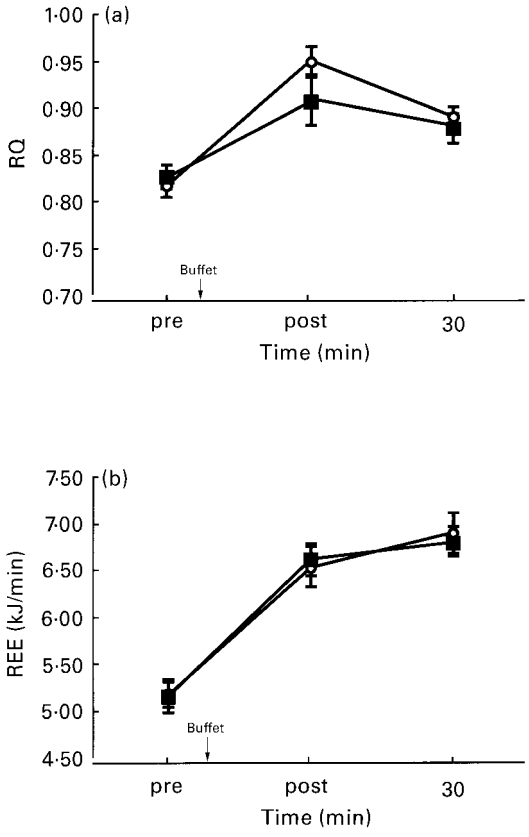

Fig. 2. Variations in (a) respiratory quotient (RQ) and (b) resting energy expenditure (REE) over time immediately before (pre), immediately after (post) and 30 min (30) after two sessions of self-selection from a buffet-type meal. Values are means for fourteen male subjects with standard errors of the mean represented by vertical bars. Repeated-measure ANOVA with session (S) and time (T) as the within-subject measurements was used to determine whether there were differences between sessions A (○) and B (■) over time and the interaction effect of S and T (S×T). RQ: S, $P=0{\cdot}33$; T, $P=0{\cdot}0001$ and S×T, $P=0{\cdot}18$. REE: S, $P=0{\cdot}96$; T, $P=0{\cdot}0001$ and S×T, $P=0{\cdot}80$.

meal, was much higher than the intra-subject variability (CV_{WS} of about 10 %) which demonstrates an individual reproducibility in energy and macronutrient intake between sessions A and B. The lack of significant differences between the two sessions in fullness and hunger measured over time before and after the buffet also revealed significant reproducibility (Fig. 1). Indeed, in response to the meal, fullness and hunger significantly fluctuated over time and no session×time interaction was observed. A strong linear correlation was shown between individual measurements in sessions A and B for fullness (r_i 0·99, $P=0{\cdot}0001$) and hunger (r_i 0·98, $P=0{\cdot}0001$) levels for measurements obtained over time by VAS immediately before (pre) and 0–240 min after the buffet. There was no significant correlation between hunger and energy intake within session A or B immediately before and immediately after the meal.

As expected, RQ and REE significantly increased after the buffet because of an increase in carbohydrate oxidation (Fig. 2). An inter-reproducibility of the two sessions in RQ and REE (no significant difference between the two sessions) and significant intraclass correlation (intra-subject reproducibility) between individual measurements in the two sessions (r_i 0·90, $P=0{\cdot}0001$ for RQ and r_i 0·98, $P=0{\cdot}0001$ for REE) for values obtained over time immediately before (pre), immediately after (post) and 30 min after the buffet were also observed. Carbohydrate oxidation significantly increased while lipid oxidation decreased immediately after the buffet and a lack of significant differences between sessions A and B for carbohydrate and lipid oxidation was also observed (Fig. 3). There was no interaction effect of session and time on RQ, REE, as well as carbohydrate and lipid oxidation. As for macronutrient intake, there was a significant correlation in carbohydrate (r_i 0·95, $P=0{\cdot}0001$) and lipid (r_i 0·98, $P=0{\cdot}0001$) oxidation individual measurements between the two sessions for values obtained immediately before, after (post) and 30 min after the buffet. In addition, there was no relationship between lipid oxidation and lipid intake immediately before, immediately after as well as 30 min after the buffet. Conversely, carbohydrate oxidation positively correlated with carbohydrate intake immediately after (post) and 30 min after the buffet (Table 4).

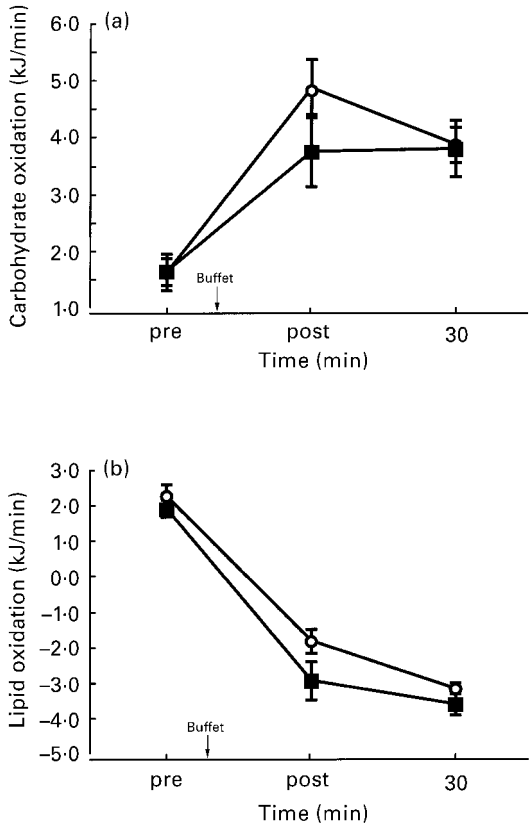

Fig. 3. Variations in (a) carbohydrate and (b) lipid oxidation over time immediately before (pre), immediately after (post) and 30 min (30) after two sessions of self-selection from a buffet-type meal. Values are means for fourteen male subjects with standard errors of the mean represented by vertical bars. Repeated-measure ANOVA with session (S) and time (T) as the within-subject measurements was used to determine whether there were differences between sessions A (○) and B (■) over time and the interaction effect of S and T (S × T). Carbohydrate oxidation: S, $P=0{\cdot}19$; T, $P=0{\cdot}0001$ and S × T, $P=0{\cdot}18$. Lipid oxidation: S, $P=0{\cdot}08$; T, $P=0{\cdot}0001$ and S × T, $P=0{\cdot}71$.

Discussion

The results of this present study provide evidence that the use of a buffet-type meal is a reproducible method to assess macronutrient preferences in the laboratory. This was mainly supported by the lack of significant differences between the averages in sessions A and B (inter-reproducibility) for energy and macronutrient intake and by significant intraclass correlations for all variables shown in Table 3 (intra-reproducibility). These results suggest that food intake tends to remain stable from one session to the other when a buffet-type meal is offered *ad libitum*. Of particular interest was the fact that energy and lipid intake were strongly reliable as the intraclass correlation coefficient for these two variables was very high, which means that subjects had the same total energy and lipid intake in the two sessions. To generalize these observations that were made in healthy male subjects, this study should be repeated in women, adolescents or persons suffering from extreme conditions such as obesity or anorexia where food intake is altered.

The low CV_{ws} of 10 % represents the low variability of energy and macronutrient intake of each subject's food intake between the two sessions, supporting the reproducibility of a buffet-type meal, and the high CV_{bs} of 40 % underlines the different pattern of food selection and the biological differences between subjects. Indeed, this confirms the idea that even in the controlled and restricted environment of a laboratory, the context of a buffet-type meal allows subjects to express their own individual food selection pattern. The findings of this study are in agreement with results reported by Obarzanek & Levitsky (1985) who also found a CV_{ws} of 10 % when subjects ate in the laboratory and demonstrated that eating in the laboratory is representative of habitual food intake. Finally, the significant reliability of fullness and hunger, two important indicators of feeding behaviour that are generally used to provide some complementary information when predicting subsequent food intake, yielded additional evidence that food intake was reproducible in the buffet-type meal.

The distribution of energy intake among carbohydrate, lipid and protein was representative of a western diet. Lipid and carbohydrate intake during buffets both corresponded to 41–42 % energy intake, which is comparable to a North American diet (Friedman, 1990). These results also suggest that the buffet-type meal is not only reliable but also represents a satisfactory testing condition to measure real macronutrient composition of daily food intake. Although the use of a buffet to detect energy and macronutrient intake is not fully representative of free-living conditions, it allows precise measurements of energy and macronutrient intake over short periods of time. As previously investigated (Westerterp-Plantenga *et al.* 1996; Bellisle *et al.* 1998), it is useful to analyse foods further on the basis of their taste composition since a major determinant of food selection seems to be individual food preferences (Stubbs *et al.* 1999). In the present study, the buffet was composed of foods chosen to represent free-living conditions and to investigate energy and macronutrient intake and not food selection related to taste. Further research would be relevant to investigate not only macronutrient intake but also taste that always plays a role in influencing food choice and selection patterns.

Table 4. Relationships between carbohydrate oxidation and carbohydrate intake and between lipid oxidation and lipid intake for the mean of two sessions of self-selection from a buffet-type meal (*n* 14)

	Immediately before the buffet		Immediately after the buffet		30 min after the buffet	
	r	*P*	*r*	*P*	*r*	*P*
Carbohydrate oxidation (kJ/min) *v.* carbohydrate intake (kJ)	0·09	0·76	0·56	0·04	0·56	0·04
Lipid oxidation (kJ/min) *v.* lipid intake (kJ)	0·34	0·24	0·11	0·71	0·09	0·76

The overfeeding generally observed in the laboratory when subjects have *ad libitum* access to a variety of foods (Rising *et al.* 1992; Larson *et al.* 1995*a*) could be the result of the spontaneous overdrive of humans to eat more when food is offered *ad libitum*. In a buffet-type meal, a variety of foods is necessary for the determination of differences in diet composition and macronutrient selection patterns of humans. On the other hand, a wide variety of foods could lead to an increase in food intake (Larson *et al.* 1995*a*,*b*). In that respect, we tried to use a reasonable variety of foods to be able to detect macronutrient preferences but we observed that this variety of foods was probably sufficient to increase spontaneous food intake. Indeed, energy intake during a buffet was about 7000 kJ in a recent study (Imbeault *et al.* 1997) and a comparable intake level was recorded in the present study, which is close to the estimated average daily energy intake of these subjects (about 10 500 kJ/d, about 1·4-fold their resting metabolic rate), indicating that subjects ate more than under free-living conditions. This spontaneous overfeeding could be a limitation of the use of a buffet-type meal in a context where the measurement of representative daily energy intake is important.

The context of a buffet-type meal permits assessment of the physiological effects of food intake on RQ, REE and substrate oxidation rates that demonstrated significant reproducibility between the two sessions of buffet-type meals (inter-reproducibility) and also between individual measurements (intra-subject reproducibility). Food intake increased respiratory exchange ratios from approximately 0·82 before the buffet to 0·93 immediately after the buffet which favoured a decrease in the rate of lipid oxidation and a rise in the rate of carbohydrate oxidation. It is known that a relative increase in total oxidation rates results in a decrease in food intake, whereas a diminution stimulates energy intake (Friedman, 1990). In the present study, preprandial levels of carbohydrate and fat oxidation were not predictors of subsequent macronutrient intake. According to Stubbs *et al.* (Stubbs *et al.* 1993, 1997), this may mean that variations in macronutrient stores, particularly carbohydrate, were not a significant determinant of *ad libitum* energy intake in the present experimental context. Moreover, as previously documented by other investigators (Thomas *et al.* 1992; Westerterp, 1993) lipid intake did not correlate with lipid oxidation after the buffet ($P > 0{\cdot}05$), but carbohydrate intake correlated with postprandial carbohydrate oxidation ($P < 0{\cdot}05$). This agrees with the concept that the body does not acutely adjust lipid oxidation to lipid intake but adjusts more rapidly carbohydrate oxidation to carbohydrate intake (Flatt *et al.* 1985; Westerterp, 1993). The absence of a significant relationship between lipid intake and lipid oxidation suggests that overfeeding with lipid is channelled to fat stores and this possibly leads to weight gain. This is supported by the fact that lipid oxidation was reduced after the buffet in contrast to carbohydrate oxidation which was increased, which is also concordant with results reported by other investigators (Flatt *et al.* 1985; Larson *et al.* 1995*a*,*b*).

In summary, energy and macronutrient intake, RQ, REE and substrate oxidation showed significant reproducibility under controlled conditions using a buffet-type meal in male subjects. A buffet-type meal can thus be considered as a reliable, accurate and sensitive test to assess the *ad libitum* food intake of healthy men with normal body weight when there is free access to food. Furthermore, the buffet-type meal could be useful for experimental testing of the effects of preload test meals on subsequent food intake.

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